IRC:138-2023

GUIDELINES FOR HIGHWAY ENGINEERS ON DISASTER RESILIENT GREEN HIGHWAYS IN MULTI-HAZARD ECOSYSTEM

INDIAN ROADS CONGRESS
2023

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Published by:

INDIAN ROADS CONGRESS

Kama Koti Marg,
Sector-6, R.K. Puram,
New Delhi-110 022

DECEMBER, 2023

Price : ₹ 300/-
(Plus Packing & Postage)

IRC:138-2023
Guidelines for Highway Engineers on Disaster Resilient Green Highways in Multi-Hazard Ecosystem

Author's Name
Indian Roads Congress

Published by
Indian Roads Congress

Publisher's Address
Kama Koti Marg, Sector-6, R.K. Puram, New Delhi-110 022

Printer's Details
Dee Kay Printers, 5/37A, Kirti Nagar Indl. Area, New Delhi-110 015

Edition Details
First Published: December, 2023

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600 Copies

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GUIDELINES FOR HIGHWAY ENGINEERS ON DISASTER RESILIENT GREEN HIGHWAYS IN MULTI-HAZARD ECOSYSTEM

1. PREAMBLE

1.1 The need for improvement of Disaster resilient highway engineering practices by learning from the past experience, out-of-the-box thinking, and innovative technology-driven engineering interventions in the planning, design, construction, and maintenance is increasingly being felt across the globe. Given India's international commitment to Sendai Framework (2015-2030), Sustainable Development Goals, and its own National Disaster Management Plan released in 2016, it is our national obligation and an opportunity to deliver roads that are safe, green, and sustainable. At this cusp of transformational change and the rapid pace of highway development, we should aim at not only building safe, green, and sustainable roads but also aim to ensure that the existing road network, especially in the areas of fragile ecology, is made disaster resilient.

1.2 The aim of achieving sustainable highways continued to capture the imagination of highway engineers with the urge to transform planning, design, and construction practices in highway sectors. Experience of building roads and highways in terrains of extreme diversity and environmental fragility repeatedly taught us that roads, highways, and the associated infrastructure could not be sustainable unless they are also disaster-resilient by additionally taking into account the site-specific complexities and challenges posed by multiple hazards.

1.3 Besides being cost-effective and time-sensitive, it is essential that roads and highways are disaster- resilient green highways against multiple hazards they are likely to face during their service lives. National Disaster Management Plan (NDMA, 2016)and the other Guidelines issued by the NDMA chiefly deal with individuals hazards such as earthquakes, floods, landslides, and avalanches. The new challenge before the highway engineers is to anticipate plausible multi-hazard scenarios associated with the highway routes and ensure that highways remain safe and resilient to multiple hazards at all times.

1.4 Nature-friendly engineering interventions are superior and most essential for disaster resilient green highways. Nature-friendly interventions for slope protection are preferred because they, by design, aim at internally strengthening the potentially unstable slope masses in hazardous areas. Most of the problems of highway failures arise because of the altered catchment hydrogeology resulting from the altered landscape due to construction and the consequently impaired drainage. In simple terms, precedence should be given to nature-friendly road protection works, which cause the least or no disturbance to the drainage characteristics of the catchment and recourse to structural measures should be taken. Both the short and long-range adverse impacts of highway construction on the ecosystem should be mitigated and countered by the greening of highway routes.

1.5 This document is duly finalized by discussion and presentations in several meetings, and rigorous review held on the shared draft document by the members of the Disaster Management Committee (G-5) for the year 2018-2020 and for the year 2021-2023. The valuable

contribution made by each member of the committee is gratefully acknowledged. The present Guidelines is aligned with India's commitment at the recent Conference of Parties (COP26), Glasgow along with the targets of Sustainable Development Goals (SDGs) and Sendai Framework for Disaster Risk Reduction (SFDRR 2015-2030).

1.6 During the 3rd Meeting of G-5 Committee held on 11th September, 2022, the draft of the Guidelines was approved for submission to the GSS Committee.

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1.7 The General Specifications and Standards Committee (GSS) considered and approved the draft Guidelines in its meeting held on 23rd September, 2022 for placing it before Executive Committee and IRC Council. The Executive Committee in its meeting held on 7th October, 2022 considered and approved the same for placing it before the Council.

1.8 The IRC Council in its 223rd Council Meeting at Lucknow (Uttar Pradesh) held on 8th October, 2022 considered and approved the "Guidelines for Highway Engineers on Disaster Resilient Green Highways in Multi-Hazard Ecosystem" for printing.

2. NEED FOR THE GUIDELINES

2.1 Roads are the arteries of a nation that organically link cities, towns, and even the remotest of the human settlements in terrains of abundant biodiversity. They connect areas of strategic importance and serve as lifelines, especially during times of crisis. The health of a road network is usually being regarded as a good indicator of the level of national development and the health of its economy. Besides being disaster resilient and safe, roads must also keep the landscape green so that it gets fully integrated with the environment and improve the quality of life.

2.2 The need for the guidelines integrating the green highway concept in disaster –resilient roads in the planning, design, construction and maintenance has arisen to efficiently control degradation of the environment. There is need to tune the current highway engineering design practices for incorporating the lessons learnt from the past and reflect on the way forward. The change over from the conventional to disaster-resilient green highway design practices is no longer an option because India stands committed to aim at sustainable development and is a signatory to the related global treaty to which the Green Highway Policy 2015 (GHP 2015) of the Government of India, is well-aligned.

2.3 It is desirable to adopt incremental improvements, wherever considered necessary, in preparations of Detail Project Reports (DPRs), Environmental Impact Assessment reports (EIAs), and in detailing out of engineering interventions. The approach has the advantage that it can be adopted in the natural course by setting higher standards in the investigation, planning, design, construction, and maintenance using environment-friendly technologies.

2.4 India needs to prepare a road map and create some pace-setting examples based on real-life highway project success stories to trigger the much needed snowballing effect. For this purpose, inter alia, we do need multi-disciplinary teams of experts, State-of-the-Art level Standard Operating Procedures, Design Manuals, Revised Guidelines on EIA and DPR's and Codes of Practice for planning, design, construction, and maintenance of Green Resilient Highways (GRHs) in multi-hazard eco-system.

2.5 The weakest links in the chain of operations fundamental to the disaster-resilient highway and highway infrastructure development engineering relate to

a) a credible projection of anticipated disaster scenarios and mapping of consequent vulnerabilities

b) composite impact of single/multiple hazards in terms of the various ways in which site-specific highway failures could occur

c) quantification of the adverse effects of hitherto neglected factors such as urbanization, deforestation, altered drainage, and Climate change as boosters of hazard levels and highway vulnerability.

For instance, extreme weather events attributed to climate change provoke slope failures and trigger landslides, pointing to a direct connection between intense precipitation and greater incidences of landslides in hilly areas. Likewise, the rising sea levels due to climate change get associated with the rising fury of cyclonic storms, coastal waves, and flooding, which add to disaster vulnerability of India's coastal road networks.

2.6 These guidelines presented in this document are meant to help achieve the much sought-after integration of transportation functionality with ecological sustainability by recourse to science, technology, and innovation; thus supporting a culture of resilient highway engineering practice. When that happens, we will also see more and more environment-friendly blue-green technologies in place of grey technologies.

2.7 Guidelines are also needed to make the practicing highway engineers fully aware of the current ground realities, lessons from past experience, and pitfalls in the conventional approach. Lack of geo-hydrological and geotechnical sensitivities, lack of appetite to harness the power of scientific investigations in development planning and inadequate attention to State-of-the-Art, smart and environment-friendly technologies are some of the major concerns addressed in the Guidelines.

3. OBJECTIVES OF GUIDELINES

3.1 The objective of these guidelines is to advance the ideas and initiatives currently underway towards establishing a culture of safety and sustainability in multi-hazard resilient highway planning, design, construction and maintenance. It also avails of the opportunity to pause and ponder over the environmental sensitivities, past experiences, design uncertainties and knowledge gaps in the current approaches and propose guidelines to give a fillip to wholesome and integrated approaches in highway sector.

3.2 The real insights for improving the highway engineering practices have come from lessons learned, especially from road failures. It is only by filling up gaps in current design approaches and accounting for the headwinds of a new set of problems arising from extreme weather events, the rapid pace urbanization and development that design engineering practices and project implementation strategies can be reshaped.

4. SCOPE OF GUIDELINES

4.1 There are usually multiple options in approaches to planning, design, construction and maintenance of a proposed highway. Wherever the road pass through hazardous areas, disaster resilience is achieved by providing various types of structures. The innovation and efficacy lie in maximizing the gains through environment-friendly engineering interventions so that structural measures are undertaken only to achieve the margin of safety as per the prescribed design. The scope of these guidelines are :

4.1.1 Recourse to eco-friendly planning, design and construction anchored to a thorough and credible site investigation; and ensuring minimum interference to topography and hydro-geology of the catchment areas to minimise vulnerability to disasters;

4.1.2 Reducing the destabilising forces and increasing resisting forces using a judicious mix of structural and non-structural measures.

5. GREEN RESILIENT HIGHWAYS IN MULTI-HAZARD ECO-SYSTEM

Green Resilient Highways (GRHs) in a Multi-hazard Ecosystem supplements the best of the highway engineering expertise and practices across the globe, even in this age of unprecedented developments in the field of science and technology. The Indian challenge is indeed daunting for several reasons. Status-quo mindsets, absence of the culture of multi-disciplinary teamwork, tardy techno-legal regime and lack of accountability are some of the reasons. The other big challenge is to foster, promote, and sustain engineering interventions and practices sensitive to and respectful of environmental concerns and multi-hazard threats.

GRHs, additionally, can trigger green livelihoods with positive effects on the community economy and risk resilience. Eco-engineering approaches for GRHs in disaster-prone areas have the potential to improve risk resilience. Cultivation of water-rich crops during heavy monsoon and slope stabilisation with deep-rooted vegetation is an apt example of eco-engineering interventions. Acceptance and involvement of the community ensure eco-engineering initiatives to be sustainable as they bring traditional wisdom to advanced data-based project management.

The GRHs will be the face of the highway engineering of tomorrow and naturally, the earlier we pay attention to it, the better. These GRH's technologies will continue to develop based on new knowledge and feedback experience, eventually aiming at the culture of construction of disaster-resilient green highways.

5.1 The Drivers of the New Paradigm

5.1.1 The difference between the design of a highway as conventionally being understood and the design of a highway, which is disaster-resilient, lies in the care of detail exercised in highway investigation, analysis, planning, design, construction, and maintenance. When highways get built without sensitivity to the understanding of nature, magnitude, and distribution of hazards to which it will get exposed during its service life, it cannot be disaster resilient. Engineering of disaster-resilient highways, must therefore, necessarily consider disaster mitigation measures as an integral part of the development planning process. It is time that the development strategy of GRHs, EIA reports, and DPRs, all act synergistically to drive the change.

5.1.2 The credibility of the investigation, planning and design data and care of detail exercised in examining various possible options of a highway route selection to pick the best one are two vital factors that have a telling effect on sustainability. The practice of arriving at optimizations based on considerations of connectivity, length of the road, cost economics, construction time required, and employment generation shall also include considerations of instabilities in multi-hazard scenario.

5.2 Insights into the Long Journey Ahead

5.2.1 Highways in India face multiple challenges exasperated by factors such as rapid pace of development, population growth, rising trends of unplanned urbanisation, overloading and mounting resource crunch. The problem becomes particularly daunting when highways pass through hazardous areas threatened by extreme weather events, cyclones, cloud bursts, floods, earthquakes, landslides, avalanches, tsunamis, extreme heat events, and poorly-engineered construction. Problems arising from road accidents, poorly maintained storm water drains, leaky water supply lines, overflowing sewage systems, piles of construction debris, wildlife movement, etc. are known to disrupt highway traffic.

5.2.2 Highways traversing through hills and coastal areas are even more vulnerable to anthropogenic and geo-climatic factors and the rapid pace of development. The time and cost over run in highway development projects involving the widening of roads in the hazardous regions of fragile ecology can be avoided by integrating disaster mitigation with development planning.

5.2.3 There is the need for a legal framework to regulate physical development along the highways in as much as minor amendments in Acts may not be adequate. As per the latest notification of Coastal Regulation Zone (CRZ-III, 2019), on the seaward and landward side of the National or State Level Highway routed through the 'No Development Zone", temporary tourism facility development including resorts and hotels may be permitted subject to the existing regulations of the concerned State. It is essential to analyze the implications of such authorization.

5.3 A Critique of the Past Experience and the Current Scenario

5.3.1 There is a dire need for resilient roads and highways in India. Earthquakes, landslides, avalanches, floods, cyclones, coastal waves, and such other disasters, besides taking a heavy toll of human lives, destroy roads and the associated infrastructure and inflict far-reaching socio-economic damage. In disaster-prone areas, initial impacts of heavy construction may appear unremarkable, but, if neglected, the situation may get out of control, and eventually, losses could be high to alarming.

5.3.2 In the worst-case scenarios, the various hazards concatenate to hit hard, many times in a row, setting the clock of development backwards by decades. For instance, melting of glaciers at the higher altitudes can create glacial lake outburst floods, which may, in turn, trigger flood induced landslides to affect high altitude roads. The landslides, besides hitting the roads directly, often block the rivers or their tributaries, creating landslide dams, inflicting more damage to roads in the lower reaches. We can have more safe roads if we pay attention to following:-

i) Attention needs to be paid in anticipating the problems, understanding of risks and lack of exposure to multiple hazards through a scientific study of highway routes right from the planning stage.

ii) Lack of understanding the uncertainties of input data, the credibility of design assumptions and serious limitations of the planning and designs. The culture of independent peer reviews needs to be made obligatory.

iii) Non-insistence on multi-agency coordination and introduction of flexibility in design modifications when amendments become essential because of the unforeseen situations and encounter with unknowns during construction.

5.4 Disaster Prone Highways in Hilly Areas

5.4.1 In hilly areas, concern for disaster resilience gets heightened by the persistent threats of road failures because of landslides, avalanches, earthquakes, floods, urbanisation and non-engineered construction. Landslides and other mass movements are among the major hydro-geological hazards threatening roads, especially in the Himalayas, the North-eastern hill ranges, the Western Ghats, the Nilgiris, the Eastern Ghats and the Vindhyas. India's northeastern region, the Darjeeling district of West Bengal, Sikkim, Tripura, Meghalaya, Assam, Nagaland, Mizoram, Manipur and Arunachal Pradesh are all landslides prone. In Uttarakhand too, landslide and flood disasters have repeatedly played havoc with the road network.

5.4.2 There are a number of sites in the hilly areas perennially under the threat of landslides. Some of these areas have become highly vulnerable to hazards over long periods of time. The remedy in such cases is not easy to find without a considerable investment of money and time for introducing science-based robust design approaches and bio-engineering in slope stabilisation. Roads on the hills must be so developed as to integrate well with the existing environment causing least interference with the catchment hydrology and natural drainage. Ground velocity and duration of shaking experienced during the occurrences of large magnitude earthquake events are considered to be better indicators of landslide susceptibility under seismic conditions for highway engineers. Critical acceleration of a slope is also an important factor in deciding the seismic safety of a slope. The factor of safety during an earthquake may drop below one (limit equilibrium state) for a short duration of time, but that will seldom destabilise the slope. When a slope fails as a rigid body, the acceleration is assumed to be constant over the entire slope, and usually, it refers to the horizontal component of the slope surface acceleration.

5.4.3 Failure of a road may trigger retrogressive slope failures on the uphill side and progressive slope failures on the downhill side. Unless such possibilities are anticipated and provided for in the road design, and quality control measures are taken during various stages of construction, such roads cannot be disaster resilient. Since progressive and retrogressive failure takes place over a period of time, from the safety point of view, regular inspections and maintenance should be made a mandatory requirement.

5.4.4 When a site demands cut and fill works in road construction, attention must be paid to the possibility of differential settlement because a part of the road may rest on natural soil and the remaining part on the fill. Global Stability analysis need to be done for all cut & fill stretches with conditions of static, saturation, drawdown and seismic as per IRC:75 and other codes. Special care is required to ensure that road design, and construction in such cases does not interfere with the natural drainage of the area, and wherever such disturbances seem unavoidable, additional drainage measures and their long term solutions are made an integral part of the highway planning and design. Merely provision of lined and unlined roadside drains is not enough. Drainage of area need to be studied for at least 2.5 km on both side of centre line or as per catchment area of cross drainage structures, whichever is more on topo sheets / DEM (Digital Elevation Model) from satellite imagery. Poor slope drainage invariably causes excessive overland flow as well as seepage of a large quantity of water by infiltration which in turn leads

to a hazardous buildup of pore water pressure within the slope mass, and to the consequent destabilisation of the slope. It is, therefore, important that investigation of sites for the design of roads must take into account all the site-specific geomorphological, topographical and hydrogeological features.

5.4.5 The road needs special attention when they cross water bodies, involve deep cuttings and connect villages in the vicinity of springs or small streams or when they run along the tributaries. The major rivers in the hilly areas generally flow deep in the valleys. Diversion without detailed study of rivers and natural water streams during the process of construction for development, urbanization and housing often leads to failures by impaired drainage, flooding and land sliding.

5.4.6 Snow avalanche protection structures need to be developed after a thorough investigation and adequate understanding of the avalanche hazard history of the area, the mechanism of the avalanche formation and the anticipated risk potential. The Snow & Avalanche Study Establishment (SASE) has enormous experience in dealing with avalanches. It has developed a system of reporting warning to facilitate safe movement of vehicle/ personnel in the avalanche threatened areas. Protection measures such as avalanche protection structures, snow deflectors, snow barriers etc. are some of the common measures adopted towards achieving avalanche risk resilience. It may be noted that, in the event of an avalanche, the reaction time available to move to a safe place is generally very short. It is for this reason that expenditure on early warning , prompt response, prompt rescue and on technology for exhumation of victims and dead bodies should be considered as an essential investment in safety.

5.5 Disaster Prone Highways in Coastal Regions

5.5.1 Development of the network of roads and highways in the coastal regions have always been a national priority, chiefly driven by an increase in population, urbanisation, agriculture, industrialisation, port connectivity, trade and other commercial activities. India's nearly 7500 km long coastline is highly vulnerable to tropical cyclones, high winds, tsunami, flooding due to storm surges, inundation and coastal erosion which is why it has never been a simple exercise to deliver disaster-resilient roads. Highway engineers also need to understand the dynamics of coastal hazards exasperated by sea-level rise, extreme weather events and climate change. Experience has taught us that highways and railroads across lowlands are frequently flooded during the high tides. Storms and sea-level rise will only worsen the situation in estuaries which get threatened by storm surges as water funnels into a gradually narrowing arm of the sea. For achieving resilience, the levels of roads may have to be raised, besides providing other protective measures. For bridges across the water in tidal zones, the rise of water level may prove to be catastrophic. Coastal Zone regulations need to be studied and adhered to for ensuring climate resilient sustainable designs.

5.5.2 Coastal areas need special sea protective works to be safe against cyclones, tsunami and rough sea conditions. Sea protection walls and Groyens are among the most commonly constructed coastal protection works. Due to non-availability of required quantity of stones for construction, as for example , at a location on the Kerala Coast, the technology of Geo tubes is being used for the construction of Groyens.

5.6 The Lessons Learned and the Way Forward (Fig. 1)

5.6.1 The Indian experience in the construction of roads and highways is rich with lessons learned, but admittedly the benefits can accrue only if these lessons are converted into credible practices ready to be ploughed back in future planning and designs.

5.6.2 The lessons to be learned from past example are listed below:

i) In single-lane stretch of highway in hills which is unsafe at several locations from slope instability point of view, any decision to widen it should be taken by raising the level of design engineering which will ensure safety, disaster resilience and sustainability. If that is not done then the more than two dozen landslides which currently threaten the highway will grow in size and many more will be added, if and when a decision is taken to widen the road.

ii) Small slope failures grow and become big in size and devastating power when slopes get disturbed. A little more provocation due to construction will invariably lead to the reactivation of old and dormant landslides and development of new ones. Slopes can and do fail in a number of ways depending on slope characteristics and the interplay of causative factors. Therefore, there is a need of designing the slopes with sensitivity so as to avoid failure of roads in multiple ways.

iii) Whenever road failures, damages or other problems are encountered, these are dealt with individually as a part of road maintenance strategy. In other words, the routine highway engineering practice instead of aiming at the integration of disaster mitigation and environmental protection with development planning, merely aim at fixing the problems as and when encountered. The relative merit of design options for projects in such situations should be judged exclusively by the technical soundness, environmental friendliness and disaster-resilient features inbuilt in the designs to the exclusion of other considerations which have no bearing on the safety of road.

iv) In order to scale up the current highway engineering practices, the least that is required is to make disaster resilience as part and parcel of the design approach. The switch over to environment-friendly technologies would require a change of the mindset, building of institutional capacities, training of project personnel and planned promotion of bio-engineering through the introduction of SOPs (Standard Operating Procedure), Manuals and Guidelines.

v) Roads can be engineered with extra-ordinary attention to the selection of the most environment- friendly highway route, picked out of several competitive tenable options, recourse to multi-hazard resilient design engineering practices and adoption of construction technologies in harmony with nature. If our highways are to be green and resilient to multiple hazards, the current professional practices in their planning, design, construction and maintenance will also necessarily have to be transformed to the State-of-the-Art level.

Fig. 1 Multi-tier Roads at Numerous Locations in Chamba to Bharmour Section Passing Through a Terrain of Fragile Ecology, Full of Slope failures and Landslides, needs Fixing of Slopes and Natural Drainage Areas without disturbing the Natural Features to avoid failure of Road

6. GREEN RESILIENT HIGHWAYS- 2015

The Green Resilient Highways (GRHs) is our ultimate dream destination. Naturally, every practising highway engineer must remain abreast with the rapidly evolving policies and directives of the government, the global state-of-the-art on the subject and the techno-legal regime. These Guidelines are meant only to throw light on some vital aspects which deserve to receive urgent attention

6.1 Green Highways Policy (GHP)

6.1.1. The Green Highways (Plantation, Transplantation, Beautification & Maintenance) Policy, 2015 (GHP 2015) was launched in September, 2015 with the vision to "Develop eco-friendly National Highways with participation of the community, farmers, NGOs, Private Sector, Institutions, Government Agencies and the Forest Department for economic growth and development in a sustainable manner".

Broadly speaking, GHP 2015 sets the following goals.

a) Develop a systematic framework for Integrated Green Corridor Development along with NHs

b) Build a resilient ecosystem in the form of "Green Corridors" along with NHs for combating global warming and climate change effects, optimum Green House Gasses (GHG sequestration and Ex- situ conservation of native species of the region

c) Make Green Highways Mission self-sustained

d) Develop unique green corridors with aesthetic appeal

e) Reduce the impacts of the air, noise pollution and dust

f) Provide shade on glaring hot roads during summers

g) Reduce soil erosion at embankment slopes and

h) Reduce the effects of wind and incoming UV radiation

6.2 The Current Thrust of the Green Highway Policy

6.2.1 GHP 2015 aims at landscaping provisions along the highway carriageways and the median side by planting trees, landscaping, transplantation, beautification, maintenance and monitoring. This initiative is expected to yield rich dividends. Implicit in the initiative is the protection of water-bodies such as lakes, ponds, streams, rivers, wells, spring points etc. to minimise hydro-geological disturbance associated with the construction of highways and their widening, especially in the hilly areas. t is mentioned that the site- specific project report development for green highway shall comply with IRC:SP:21 "Guidelines on Landscaping and Tree Plantation" and the directives/ circular/ advisory issued by National Green Highways (NGH) Mission and its amendment thereof .

6.2.2 The following six Missions for Green Highways created across the country are:

a) Integrated Green Corridor Development and Management for upcoming highways projects

b) Green Corridor along with developed National Highways network

c) National Green Highways Mission self-sustained in the next ten years

d) Green Highways for Reinforcing India's Commitment

e) Creation of sustained employment for one lakh people and

f) Platform for Research and Innovation in Green Pathways Sector including Roads, Waterways and Railways

6.2.3 The National Green Highway Mission (NGHM) is targeting to develop all of existing NHs and 40,000 km of new roads in the next few years as Green Highways. Towards that end, a Green Highway Division was created in September, 2017 under National Highways Authority of India (NHAI). A corpus "Green Fund" with 1% of the Total Project Cost (TPC) of all NH projects has been created to ensure quality plantation and maintenance.

6.2.4 The GHP 2015 is to be regarded as a major step forward in our march towards the engineering of disaster-resilient, green roads and highways. The real challenge lies in

a) fully aligning the sensitivities of engineering interventions with the SDGs (Sustainable Development Goals), SFDRR's (Sendai Framework for Disaster Risk Reduction) goals and Climate Action priorities

b) achieving disaster resilience and sustainability in highway designs

c) putting a lid on CO_2 and other GHGs' emissions

d) minimizing environmental damages and

e) integrating transportation functionality, economic development and ecological sustainability.

6.2.5 The present initiative is being looked upon as "a voluntary, collaborative, public/ private effort designed to identify and promote streamlining and environmental stewardship in transportation planning, design, construction, and operation and maintenance through integrated partnerships, flexibility, rewards, and market-based solutions". We need to pitch the expectations much higher and aim at nothing less than green, safe and resilient highways. This will require out-of-the-box thinking to embrace environment- friendly designs

6.3 Challenges, Gaps Areas and the Road Ahead

6.3.1 Every project should pass through the rigours of investigation and site-specific engineering geological, hydro-geological, geotechnical, seismological and meteorological studies. A beginning with the right kind of expertise and focus is essential for effectively dealing with ecologically fragile hazardous zones in a multi-hazard ecosystem. Also, because of geo-climatic diversity, every single problem will have to regarded as unique, looking for a site-specific rather than a generic solution.

6.3.2 Another big challenge in hill road construction is to account for and effectively deal with huge piles of soil and rock wastes generated during the process of road construction as also during the widening of the existing roads. The piles of debris on the slopes often fuel landslides, debris flows and other mass movements, especially during the monsoon season. Besides damaging the road itself, the debris flows and other mass movements so generated may also threaten human habitations and other highway infrastructure in their zones of influence. Design of highways shall include counter measures to mitigate all such anticipated failures. It would be ideal for making use of the waste in the construction of slope, road protection works and other constructions.

6.3.3 For environmentally safe disposal and management of muck, suitable muck dumping sites which, apart from dumping waste, can also become sites for creation of desired amenities, green zones etc. must be selected judiciously considering all aspects of slope stability, ecology and environment. For example, the muck dumping sites should preferably be located on a stable slope/place, close to the muck generating locations to avoid air pollution due to dust generation and transportation but must also be away from rivers/drainage to avoid rolling of muck/loose materials into the river/drainage course.

6.3.4 Care for environmental rejuvenation, and the initiatives for water conservation in hilly areas are gaining increasing attention. Ordinarily, there cannot be any objection to such an initiative which aims at reducing overland flow, flooding and erosion by groundwater recharge. There are situations, however, in which such a move would be suicidal in the context of disaster-

resilient highway safety. Imagine water recharge initiatives on a vulnerable, seemingly unstable uphill slopes in the upper reaches of a highway. Groundwater recharge at such locations will prove disastrous if the micro-geological details of the slope mass include shear zones, slickensided slip surfaces of the old landslides and unfavourable joints and fault-lines, because of the groundwater recharge. Slope destabilizing forces will increase up on an increase in the bulk density of the slope forming materials. Slope stabilizing forces will drastically decrease because of the development of excess hydrostatic pressures on the potential surfaces of failure and by reactivation of shear zones. Simply speaking, nothing can be more dangerous than water ingress into the slopes that feeds potential slide boundaries, fault lines, weak joints, and slip surfaces of old landslides.

6.3.5 An identical situation may arise when freely draining construction materials are used to reduce the impact of flooding on a highway. Use of smart materials and technologies such as permeable asphalt, porous concrete and pavers may reduce flooding and can be used where there are no negative implications of doing so. All that one has to do is to ensure that water that recharges the slopes in itself does not become a cause of a disaster. Trench drains at edge of paved shoulder need to be provided as per study of sub-surface water flow so that pavement is durable.

6.3.6 As per the prevailing practice, the whole land acquired for the construction of highways is not fully developed. It is time the highway development policies, and planning practices are advanced to aim at effective utilization of the unused land to improve overall forest cover and connectivity besides promoting resilience against any combination of multiple hazards using environment-friendly approaches, technologies and materials.

7. GUIDELINES FOR GREEN RESILIENT HIGHWAYS INTEGRATING THE GREEN HIGHWAY CONCEPTS

7.1 Guidelines -Current Status

7.1.1 Indian Roads Congress have produced Codes, Manuals, Guidelines and Monographs, from time to time, covering the whole range of aspects including engineered site investigation, planning, design, construction and maintenance. Insofar as the engineering of Disaster Resilient Green Highways are concerned, the Green Highway Policy 2015 of the Government of India is to be regarded as a major step forward. Plantation, transplantation, landscaping, beautification and maintenance of green corridors lie at the heart of the policy, and shall be part of routine highway practice. Guidelines have also been framed for the implementation of Green Highways Projects. These guidelines shall apply to all upcoming and developed NHs regardless of their administrative agency.

7.2 Ensure multi-disciplinary expertise to steer the affairs of the Disaster Resilient Highway Projects by integrating Green Highway Concepts.

7.2.1 Planning, design and construction, maintenance of highways in a fragile eco-system face the greatest challenge of dealing with uncertainties. The engineering skills, expertise and training required to understand and deal with uncertainties are truly multi-disciplinary and of a highly specialised nature. Every major project involving GRH shall begin with the constitution of a multi-disciplinary team of experts representing disciplines of Highway Engineering, Engineering Geology, Hydro-geology, Geotechnical Engineering, Construction Engineering, and Planning

and Design. The team will engage with experts in the disciplines of Meteorology, Seismology, Environmental Engineering, Remote Sensing, Data Analysis, Instrumentation engineering and Disaster Mitigation and Management specialists, Social Scientists and Techno-legal experts as per the felt needs.

7.2.2 The Selection of Multi-disciplinary project teams should be made only after informal consultations and due diligence on the scope of work with full awareness about the anticipated headwinds of the route- specific challenges.

7.2.3 Once the profile of a project is ready for launch, Institutions such as Indian Academy of Highway Engineering and Central Road Research Institute should be commissioned to create project-specific multi- tier training programmes and train professional teams at all levels before they are deployed on the job. Agencies like NHAI should build adequate in house design capacities to do full justice with the complexities of site-specific designs. If and when necessary, the project authorities should connect with other knowledge institutions of repute through standing MoUs for independent peer-review of DPRs.

7.3 Strategic Planning for Selection of the Best Highway Route

7.3.1 Experience and literature in Highway Engineering for Selection of the best highway route have been developed for decades. IRC has published Hill Road Manual IRC: SP:48 which provides guidelines for fixing the alignment of hill roads based on administrative, developmental, strategic and other needs. It deals with methods of surveying, ground reconnaissance, preparation of maps, lateral and vertical clearances, super-elevation at curves, blind curves and such other factors. The broad guiding principles of route selection are outlined in IRC: SP:48, Inter alia, ecological fragility of terrain, multi-hazard history of the area and relative merits of different possible alignment options need to be discussed.

7.3.2 For the selection of the safest and the most productive route for a highway, it is essential that all the possible alignment options are critically examined in the light of the route-specific ecological, strategic, cultural, development and cost imperatives. Disaster proneness of the route shall be considered to prevent the same from all possible situations including earthquake, avalanches, glacial movements, landslides, heatwaves, over flooding of rivers, Tsunamis etc should be considered. Whereas the basics in a selection of a route for Green Resilient Highways remain unchanged, much higher levels of professionalism, out-of-the-box thinking with the care of detail in the investigation, planning, design and construction and multi-disciplinary inputs shall be necessary for fixing road alignments to ensure disaster resilience, to deal effectively with uncertainties, and to reduce subjectivity and eliminate chances of adhocism in decision making.

7.3.3 The conventional practice of processes leading to examining options in the selection of a highway route shall be strengthened by paying special attention to

a) the credibility of multi-hazard risk assessment

b) hazard history and persistent threats due to dormant, active and developing slides affecting the road alignments under consideration

c) pro-active strengthening and rejuvenation of slopes using eco-friendly engineering interventions, and

d) avoidance of landslide hotspots by rerouting or alternative approaches including tunneling

e) In case of requirement of cutting & filling not getting accommodated in ROW (Right of Way), realignment for four laning project need to be explored. Additional surveys & investigations need to be visualised for realignment and stability requirements which may be needed for soil nailing, shot creting, rock fall barriers etc.

f) Fixing embankment level of road adequately above the HFL (Highest Flood Level) after careful detailed study of history of flooding and HFL in the area and providing necessary number of cross drainage works with required discharge capacity so as to avoid breach of embankments.

7.4 Engineered Site Investigation Imaginatively for Disaster Resilience

7.4.1 To achieve credible and comprehensive site-specific data for delivering disaster-resilient highways, it is not enough to order a set of detailed reports covering the entire gamut of information on geomorphology, engineering geology, hydrogeology and geotechnical characteristics as mere items on an all-inclusive order book. What is really required is a field evidence-based, well-comprehended site investigation strategy plan with a focus on filling in of the knowledge gaps, throwing light on uncertainties, validating assumptions and ensuring credible data for designs through need-based, conscientiously implemented investigations.

7.4.2 Extended or additional site investigations shall be carried out to answer questions, validate assumptions and test the credibility of data critical for design. This is because the success of GRH projects invariably depends on the credibility and quality of exploratory studies and the care of detail with which their alignments are evaluated, and designs are developed after considering various alternative options. In other words, site investigation programmes for major GRH projects shall be so framed, planned, designed, detailed out and implemented that they provide additional insightful, adequate and credible data aimed at steering the various stages of the project development and facilitate decision making under uncertain premises. Further, such investments brace the thought process with evidence-based sound engineering judgment and minimize vulnerabilities.

7.4.3 An exceptional care for detail is required in conceptualizing, planning, and carrying out site investigation for credible multi-hazard risk analysis. It follows, therefore that all GRH projects shall be adequately funded and professionally managed to ensure

a) well planned, comprehensive site investigations by a multi-disciplinary team of experts involving the fields of geomorphology, engineering geology, hydrogeology, geotechnical engineering, seismology and construction;

b) production of large scale multi-hazard maps of the area aimed at the study of disaster scenarios;

c) Hazard, Vulnerability and Environmental Impact Assessment for risk analysis;

d) identification of elements at risk for pro-active fixing of problems before they could grow bigger; and

e) documentation of lessons from the past experience, success and failure stories, published papers, feedback and public response.

7.4.4 The quality and adequacy of site investigation shall be measured in terms of the soundness and credibility of its outputs and outcome. Interalia, it shall provide

a) a holistic view of the eco-system and reasonable understanding of the environmental and engineering imperatives associated with the proposed highway construction

b) engineering insights into the chain of multi-hazard causative factors arising from the various hazard maps produced to project disaster scenarios

c) identification and delineation of hazard hotspots and the current problematic stretches along the route

d) credible hazard, vulnerability and risk analysis

e) Credible hydro-geological data from the associated catchments with particular reference to a steady-state water flow regime, water bodies, natural streams, tributaries, spring points, etc.

f) design data sets with a clear listing of uncertainties, assumptions and unanswered questions.

7.4.5 During the stage of investigation and mapping, every effort shall be made to elucidate slide boundaries utilizing the information on fault planes, shear zones, discontinuities, ground cracks, areas of slope subsidence and debris-accumulation, etc. Representative undisturbed samples from the elucidated slide boundary shall be tested in the laboratory simulating the stress path representing the field condition. Excess hydrostatic pressures on boundary shears shall be estimated using the hydro-geological data.

7.4.6 There are BIS Codes which govern site investigations for routine highway projects. The scope and nature of investigations for a highway project can at best be outlined but cannot be prescribed because of the great diversity, variability and complexity of sub-ground characteristics from location to location. Where a landscape is full of deep exposures of geological materials, the best course would be to carefully log the exposed profiles and interpret them based on a tailor-made testing plan rather than go by drill hole results even without having a cursory look at such soil profiles. The planning and detailing of site investigations shall, therefore, be done by a multi-disciplinary team in the backdrop of area-specific inputs.

7.5 Green Resilient Highways, EIA and the New Awakening

7.5.1 Green resilient highways and Environmental rejuvenation and protection go together. This is the reason that for achieving GRHs, we need transformational change in the basic approach to EIA so that environmental concerns get integrated with the construction of roads. It is also important that highway surveys, investigation, planning, design, construction and maintenance are carried out taking care of environmental concerns at every stage of development.

7.5.2 All projects, big or small, aiming at GRHs construction shall necessarily go through the rigours of professionally peer-reviewed DPR, EIA and the corresponding Environment Management Plan with strict compliance. Most of the EIA studies traditionally focus on hardcore environmental concerns like carbon credits, impacts on forest cover, bio-diversity, quarrying and mining, climate change, natural water regime, and sea-level rise. EIA for GRHs, while taking note of all the currently prevalent codes, practices and guidelines, shall additionally consider many other vital factors such as hazard history of the area, seismic and other fault-lines.

7.5.3 EIAs, as generally carried out for many anticipated environmental concerns and unforeseen challenges attributed to

a) impact of construction on the fragile ecology of the landmass including ponds, lakes, water bodies, confined and unconfined aquifers, natural water streams, rivers and their tributaries;

b) reactivation potential of the various hazards to which the route is vulnerable. This would include reactivation of dormant landslides and initiation of new slope failures;

c) safety of existing infrastructure including feeder roads, human settlements, transmission line towers and other infrastructure;

d) river erosion, river bed rise etc. breach of embankments, inundation of habitation and

e) progressive erosion and destabilization of slopes.

7.5.4 Highways generally pass through terrains of a wide sweep of bio-diversity as also through areas of both known and unknown multi-hazards. Unless thoroughly appreciated, explored and understood, the EIAs generally some times escape the often serious implications of the past hazard history of the landmass, the implications of seismic fault-lines, disturbance to confined and unconfined aquifers and the associated complex groundwater regime. In other words, without the study of environmental scenario prior to undertaking a highway project, no objective assessment of the post-construction impact is possible. On the other hand, a carefully crafted EIA will provide deep insights into the environmental vulnerabilities and preparation of DPR. The study will also help in the assessment of the environment-friendly technologies to be deployed at the various stages of development.

7.5.5 EIA, need to take note of the far-reaching consequences of widely dispersed small failures along a highway route. Small failures do grow with neglect either progressively or retrogressively. Take, for example, the hilly areas littered with small slope failures. Eventually, if left unattended, the very small slope failures become landslides, and the environmental impact of landslides could be fatal. The environmental concerns will only get heightened if one were to consider all tenable modes of failure. Further, slope failures could be rotational, translational and complex. In real-life situations, however, even the isolated slope failures due to location specific geology and progressive failures due to slope toe erosion need to be considered to arrive at the worst possible scenario for which the highway is to be designed

7.6 Green Resilient Highways, DPR and the New Approach

7.6.1 Detailed Project Report (DPR) for projects aimed at GRH construction shall recognize every location as unique and prescribe location-specific designs fortified with ecologically sensitive and environmental- friendly road design and protection works based on detailed investigation and analysis. The DPRs, based on least cost (L1) some time lose sight of ground realities, fails to anticipate the problems and suffer from the disabilities expected of a poorly done job with questionable assumptions. DPR should not play blind to the implications of uncertainties in the investigation, planning, design and construction. DPRs should take advantage of field evidence, past area-specific experiences and the messages conveyed by site-specific engineering geology, hydrogeology and geo-technology.

7.6.2 DPRs often run into criticism because of virtually invisible multi-disciplinary expertise, relaxed approach in investigation and data analysis-an absence of robust Guidelines, policies, peer reviews and regulations. Many times provisions are included just to fulfil the obligatory inventory, which doesn't serve the real purpose.

7.6.3 DPR consultancy work should be awarded after stringent scrutiny of the firms, taking into account their field related (multi-disciplinary) expertise, delivery capacity and a proven record of past experience. For landslide related projects, expertise in the fields like engineering geology, hydrogeology and geo- technology lies at the core, to be supplemented by subject-specific expertise like tunnelling, road and building construction. Accreditation of consultancy firms shall be introduced to ensure the highest standards, capacities and professional ethics.

7.6.4 In every major project involving measures for disaster risk resilience, comparative analysis of competitive technological options should be undertaken in the run-up to decision making. Wherever essential and feasible, the adoption of Green Technologies should be obligatory. The report shall also justify the inclusion of green technologies, if and when essential, with clear statements on their negative environmental impacts, if any, and the proposed corrective action envisioned as a part of the design, with CBA.

7.6.5 Every DPR shall provide a plan to demonstrate how the efficacy of disaster-resilient engineering features and interventions are to be monitored beyond the construction phase for feedback to designers and disaster managers, for mid-course corrections and future use.

7.6.6 The time allocated for the preparation of a DPR shall be decided by a team of experts, on a case to case basis. The decision shall take into account factors such as inaccessibility of the site, delays due to inclement weather, the scale of the hazard, vulnerability and risk mapping work and the nature, quantum and quality of the prescribed field and laboratory investigations.

7.6.7 The scope of the work and the expected outputs of the report shall be clearly and comprehensively defined in the RFP document for appointment of a DPR consultant. It shall also include the extended scope of work, for example, mapping of surrounding areas and facilities, to arrive at landslide risk reduction measures as an integral part of the project.

7.6.8 An independent peer-review of DPR's of all major projects shall be made mandatory. Quality Cost Based Selection (QCBS) of DPR shall replace the practice of awarding work on the least cost basis.

7.6.9 Pre-audit of DPRs along with periodic surprise audits of projects in progress shall be made mandatory.

7.6.10 Provisions for drainage, trench drains, catch water drains and stability of slopes & erosion control measures need to be listed in **Schedule B** by DPR consultant as worked out keeping in view adequate investigations and design.

7.6.11 Technical agencies within the government shall be authorised to review DPRs before implementation only after ascertaining their capacities, competencies and credibility. Every effort shall be made to multiply, strengthen and nurture institutional arrangements for vetting of DPRs, such as by expert consultants before these are considered for approval.

7.7 Guidelines on Planning for Multi-hazard Risk Resilience

7.7.1 For Green resilient highways to be safe and sustainable, they shall necessarily be conceived as multi-hazard resilient at the planning stage itself. The conventional design practices should consider the fact that roads are at times threatened by two or more hazards, sequentially or together. For instance, an earthquake, besides inducing earthquake-induced first-time landslides can also reactivate dormant slides which in turn can block natural streams to cause flooding. Yet another possibility is that heat waves may lead to cloud burst and over flooding of rivers , or river flooding may in turn trigger landslides in the lower reaches of the slopes or inundation of cities near sea shores. Landslides and Other mass movements such as snow avalanches, debris flows, rock falls and liquefaction failures are generally the most visible faces of disasters on hill roads and inundation of villages, cities and damage to road network in plains due to over flooding of rivers and tsunamis in sea. If and when multi-hazard maps of highway route area are not available, reference shall be made to the large scale maps of individual hazards.

7.7.2 **Seismic and Flooding Aspect of Highway** - Seismic zone is decided as per relevant code and structures are being designed as per applicable zone and importance factor. Global stability analysis is done as per IRC:75 with different conditions such as static, saturated, draw down, seismic and combinations. If sub-soil is reasonably good as per assessment by Geo-Technical Engineer than stability of embankment is analyzed for more than 3.0 m height. However, if alignment is passing through areas with marine clay, poor c & Phi values and water table depth is within the range of height of embankment than stability analysis is required to be done including seismic condition. If factor of safety is not as prescribed, then analysis need to be repeated with stability berm / use of Geo-cell / Geo-grid or combination and balancing embankment slope.

7.7.3 Hydrology of project need to be analyzed for wider corridor using topo sheets or satellite imagery & DEM. Adequate cross drainage structures need to be provided and as per catchment area and linear water way requirements, hydraulic model study need to be done to minimize impact of heavy rains & effect of flooding. Erosion control measures such as turfing, pitching, drainage chutes, L-Kerbs, geo-green blanket etc. need to be provided by DPR consultant as per soil conditions and rain fall data. Energy dissipation basin need to be properly designed and aligned with drains. Stagnation of water along embankment need to be avoided and suitable embankment toe protection need to be provided. In hilly areas, catch water drains and trench drains need to be provided. Hill cut slopes need to be analyzed by geo-technical engineer and suitable measures as per slopes such as shot-crete, gabion facia, soil nailing, anchor bolts, rock fall barriers etc. need to be provided. Stability of embankment and hill cut slopes is adversely affected during excessive rainfall and design, construction and maintenance aspects should consider all these provisions as per requirements. In difficult situations, advise of experts from vendors / independent experts should be taken.

7.7.4 For major projects involving GRHs, where hazard maps are not available, a multi-disciplinary team of experts shall be tasked to prepare such maps on a map scale of 1:10000 or larger, to be decided on a case to case basis. If more details are required to answer specific questions, demand should be raised for maps prepared at scales of 1:1000 or 1:500 and contour interval of 1-2m. Geomorphological, Geological and Hydro-geological maps should specifically address Geotechnical concerns with particular reference to fault-lines, geological discontinuities,

shear-zones, boundaries of old, dormant, and active landslides. Characterization of catchment hydrology- especially water streams, water bodies, spring points, areas of overland flow and water infiltration deserves the highest attention. Once a credible large scale multi-hazard map and the corresponding site-specific infrastructure map are available on a GIS platform, elements at risk shall be identified by the superimposition of the two and each of these elements at risk shall be considered in the design.

7.7.5 Hazard, Vulnerability and Risk Analysis based on well-engineered site investigations usually form the basis to :

a) Foresee key problem areas

b) Anticipate nature and magnitude of threats to the landscape, environment, forest cover etc.,

c) Anticipate nature and types of threats to the existing human habitat, existing roads, transmission- line towers.

7.8 Special Considerations at the Planning Stage

7.8.1 Bio-engineering for Slope-rejuvenation

Green highways, by their very nature, aim at reversing slope degradation processes, countering erosion and preventing landslides using environment-friendly technologies. For example, slope failures provoked by overland flow and runoff can be significantly reduced, and consequent soil loss can be effectively prevented by planting and growing Vetiver hedges on contours and adopting conservation tillage practices between them. Care should, however, be exercised to rule out that holdup of overland flow due to the planting of grass does not provoke sliding of slopes by a build-up of excess hydrostatic pressures on potential planes of weakness within the slope mass.

The species of Vetiver System for slope stabilization has captured the imagination of nearly 120 countries as a very effective, economic, community-based and environmentally- friendly sustainable bioengineering tool. It is now established that the roots of vetiver grass being deep, its spread over an eroding slope is akin to effectively nailing the soil cover. Once established, the Vetiver plantings (**Fig. 2**) will last for decades with little, if any maintenance. The success would lie in the quality of planting material, proper design, correct planting techniques.

7.8.2 Effective Utilization of Construction Waste

The greatest challenge in highway construction lies in ensuring the minimum cutting of mountain systems. The deep slope cuttings tend to generate a colossal amount of debris which remain unutilized posing great environment hazard. The perennially occurring slope wash and debris flows and landslide add to build piles of construction waste. Highways cannot remain all-weather and green unless the construction waste can be converted into building material for use in road construction and in development of road protection works, such as breast walls and retaining walls

Fig. 2 Vetiver Grass being Deep-Rooted Virtually nail down a Slope and Prevent Erosion resulting from Overland Flow (Source: Chandan Ghosh)

7.8.3 Harness Power of Technology for Construction of Deep Drains

The most environment friendly, effective and sustainable solutions are those which ensure efficient surface and subsurface drainage of slopes. Whereas highway engineers, in general, are well conversant with measures to improve surface drainage, attention is required to be paid to deep subsurface drainage to augment slope stability. In many cases where the buildup of excess hydrostatic pressures within a sloping mass is high, especially during short duration high-intensity rainfall events, deep-seated landslides get activated. There is no way these can be prevented or controlled unless a system of vertical and sloping deep drains are constructed to drain water from tens of meters within the problematic slope mass. The directional drilling equipment to permanently control a major earth slide by deep drainage is shown in **Fig. 3**.

7.8.4 Roadside Amenities

Roadside amenities assume high importance for all flagship disaster-resilient highway projects, especially when the route is under perennial threat of disasters. Tourists look for waterfalls, scenic spots and vantage points. Drivers look for automated traffic management systems (ATMS), fuel and service stations. Travelling public looks for hotels and restaurants, requirements of ATM machines, public telephones, mobile charging ports. Rest houses and parking places, etc., are common. The provision of following basic amenities shall be made at regular intervals on road for:

a) First-aid posts and dispensaries

b) Night shelters and parking sheds at safer places away from highly vulnerable locations

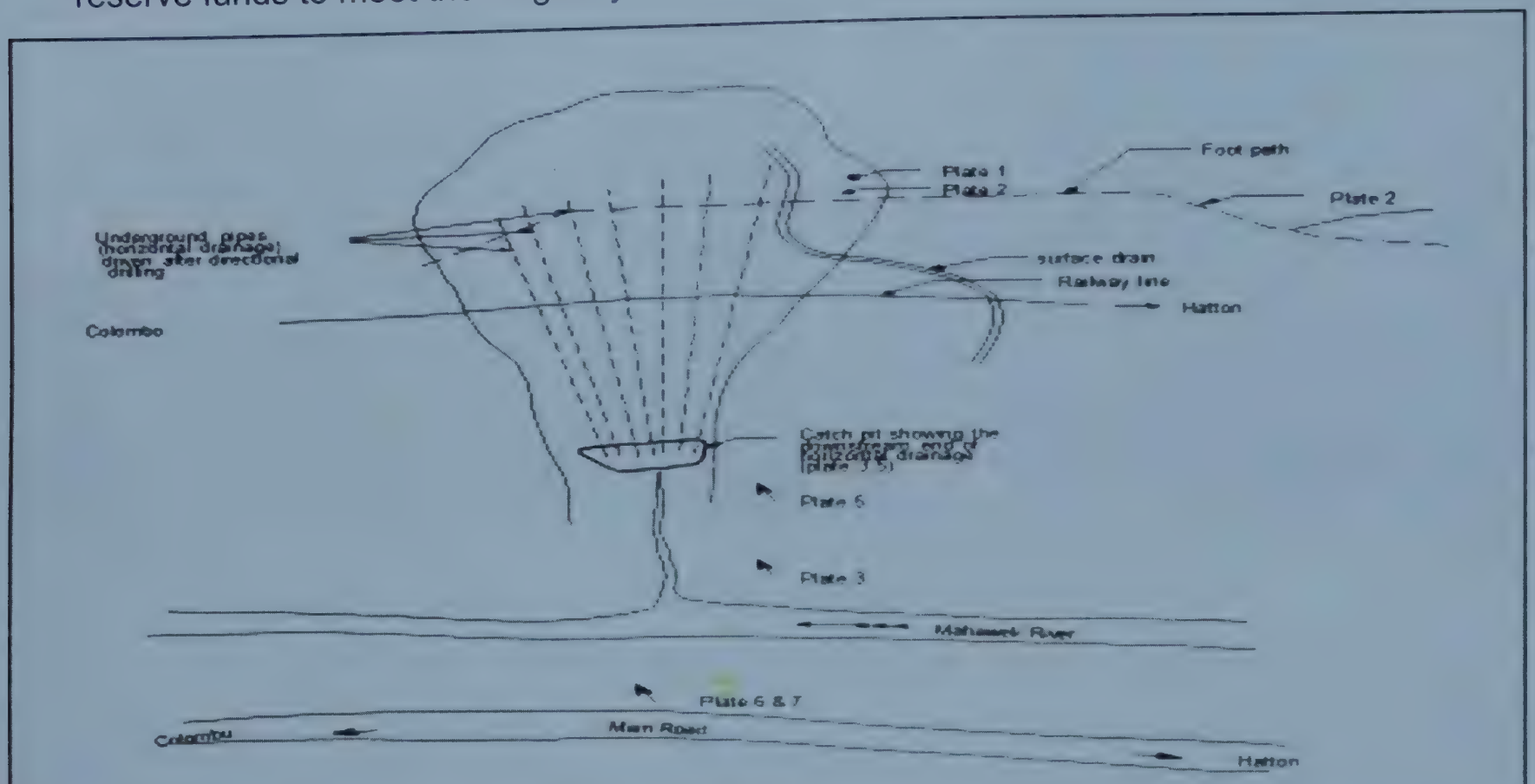
c) Parking sheds at critical locations for mass parking of vehicles during emergency

d) Highway maintenance, information and early warning centres and

e) Duly stabilized and protected Authorized construction waste disposal sites.

f) Stationing of Quick disaster response teams along with necessary infrastructure and manpower for evacuation at an interval of 50 Kms in plains and at 20 Kms in Hills

g) Mechanism for quick restoration of the road infrastructure at each block level with adequate reserve funds to meet the exigency.



Watala Landslide

Fig. 3 Plan of directly Drilled Deep Drains to release the Excess Hydrostatic Pressure in a 100 year old history of Land slide at Watawala

7.9 Integration of Blue-Green Infrastructure (BGI)

7.9.1 Blue-green Infrastructure (BGI) can boost resilience if integrated adequately with development projects. Integration of BGI with highway design is a big challenge when viewed in the context of the multi- hazard ecosystem. It is important, to begin with, the relatively hassle-free construction of highways in a hazard free-ecosystem, to understand the complexities of challenges. The GRH is based on the strength of high-quality physical planning. Highway design structurally and functionally relies on the efficacy of the median, which plays a role in regulating the traffic flow and bolstering highway safety. Median, covered with dense and medium height shrubs and hedge plantation, minimize the undesirable glare of light from moving vehicles, thereby making the traffic flow more comforting and safer. Water requirement of plantation can be met by groundwater recharge shafts laid at regular intervals.

7.9.2 Introduction of permeable green filter strips over side slopes, bio-swales along highway medians and side drains on both sides, designated infiltration or ground recharge points, rain gardens, retention and detention ponds, water link with community agricultural field, and roadside plantations will respond to the sustainable water cycle and eco-livelihoods in plain lands.

7.9.3 Side slopes next to the shoulder of the carriageway of a highway and the margin land parcels can be used to integrate the BGI as shown in **Fig. 4**. The Filter Strip shown in **Fig. 5** is uniformly graded, gently sloping, vegetated strips of land designed to accept runoff as overland sheet flow from upstream and to screen pollutants from flowing water. Filter strips are best suited to take care of runoff from relatively small drainage areas such as carriageways of roads and highways, roof downspouts, smaller bays and parking areas, and permeable surfaces. They are positioned between a hard-surfaced area and a receiving surface water collection drain. Low height plantation and local grass saplings with stone chipping are commonly used for side berm and slope protection along the highways. The low height vegetation also helps to reduce the noise generated by various automobiles at the engine level besides curbing the suspended particulate matter at the lower level. The filter strip will facilitate turbulence-free water flow disposal to bio-swale and infiltration.

Fig. 4 Bioswale running through the Median, an Effective Provision to collect the Surface Runoff from the Carriageway to recharge the Groundwater along the Highway

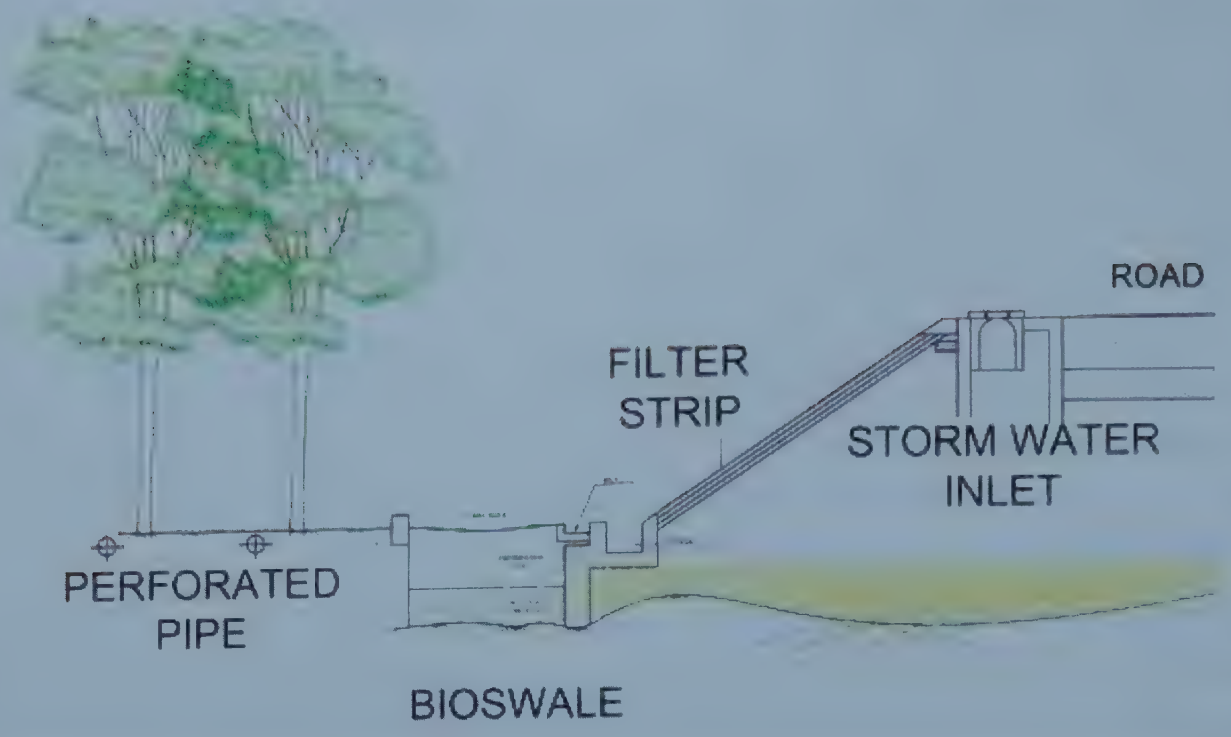


Fig. 5 Conceptual Section for Blue-Green Infrastructure for Highway Shoulder

7.9.4 Bioswales are vegetated, shallow, landscaped linear depressions along the road network. They are designed to capture, treat, and infiltrate storm water runoff as it moves downstream. Flexible siting requirements allow them to be integrated transportation strategies. Bioswales play a more significant part in enhancing the biodiversity by strengthening and preserving native ecology of the place and affords them a more diverse and pleasing appearance, besides improving groundwater recharge. Being a hybrid of blue- green spaces, they do help in improving air quality, reducing heat stress and adding aesthetic value. Presence of vegetation in the swale helps in controlling speed and amount of flow, and in improving the quality of water. The swales shall drain partially to nearby agricultural fields and plantations with recurrent water quality checks and can infiltrate at designated ground recharge points which are engineered appropriately. Residual water can be collected to nearby low depression areas which shall be identified as retention and detention ponds as the requirement and nature of the available site.

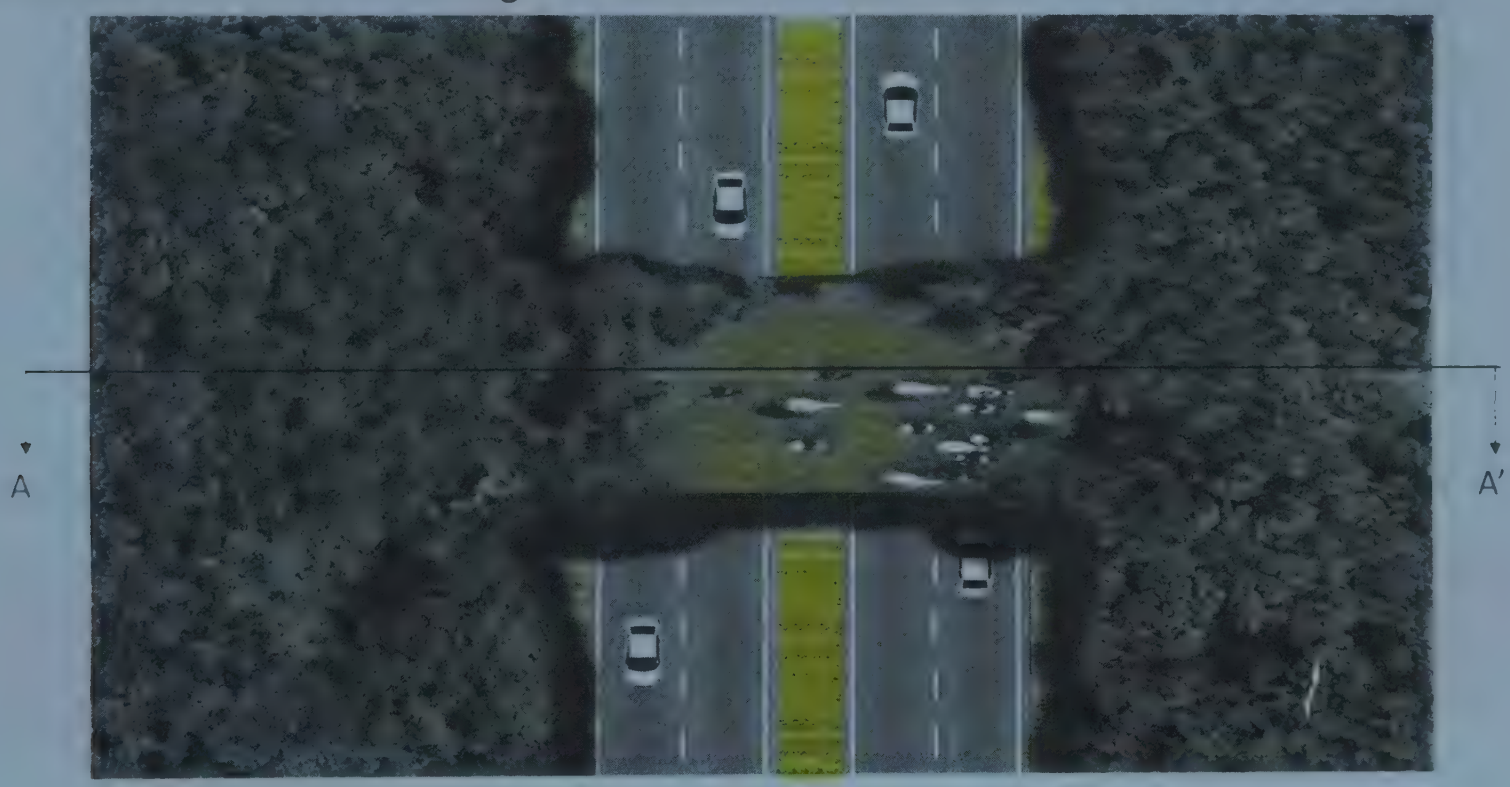
7.9.5 Where wildlife is likely to get threatened, project DPR should make a special provision for natural passages or corridors, such as the Eco-link bridge **Fig. 6** and **Fig. 7**, to facilitate hassle-free, safe and secure passage for the animals crossing from one part of the forest to another. Animals cannot be forced to use any bridge unless it gets integrated with natural habitat to encourage animal cross- over, for which several design alternatives may have to be considered. Such an initiative will also help towards restoring the ecological reunion between fragmented habitats.

7.9.6 Roads and highways being lifelines for an effective post-disaster response, it is imperative that they should remain safe to facilitate rescue, evacuation and effective communication. Road sections critical from the safety point of view shall be identified at the planning stage to demand special attention at the design stage. Critical infrastructure shall be so located as to remain stable and safe regardless of the types of hazards to which they are subjected. Sound planning can minimize blockage of roads by landslides, rock falls, debris flows and flooding. Loss of human lives and traffic delays can also be minimized.

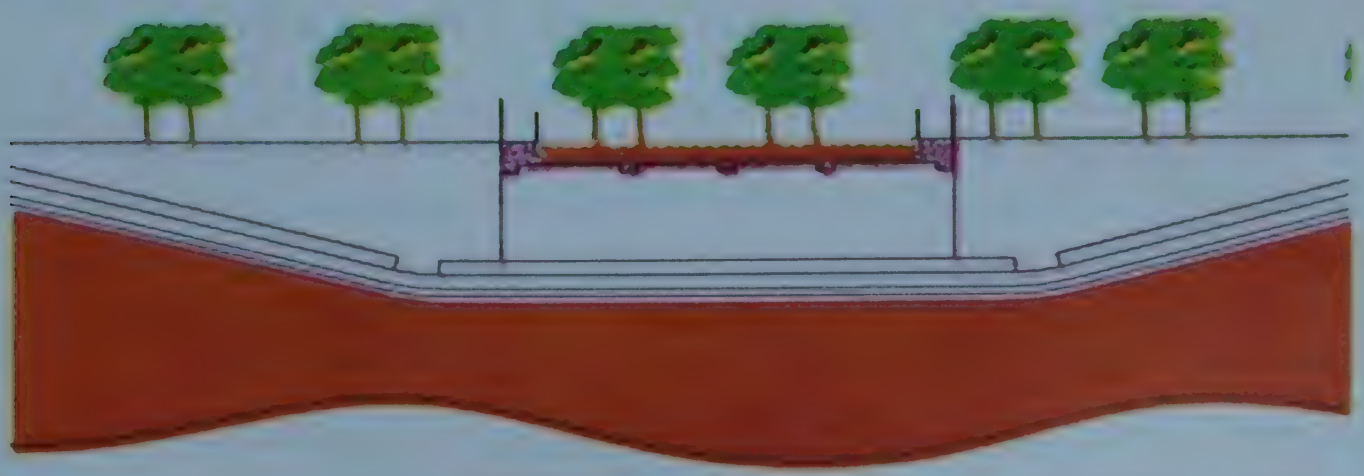
7.9.7 The roads traversing along rivers and their tributaries often suffer damages and even failures in which slope toe erosion or riverbank erosion often plays a destabilising role. Threats of river flooding, particularly in the monsoon season, are generally known. Sudden flooding in the river because of the factors such as breach of a landslide dam upstream often come as a surprise. During the planning stage itself, it should include measures to counter such imminent failures pro-actively.

7.9.8 Nature-based solutions play an important role in enhancing resilience to GRH in coastal areas: e.g. flood reduction, wave attenuation, erosion reduction, shoreline stabilization, etc.

7.9.9 For GRHs to remain evergreen and fully operational even during the times of disaster emergencies, the highway plan, at the planning stage itself shall include secondary routes to swiftly connect with the helipads, airports, parking lots and threatened human settlements, so that disaster rescue and response operations are not hampered. No matter how hard we try, the uncertainties and shortcomings because of site-specific complexities will always remain to a certain extent. This is the reason that besides including risk resilience features in design, it becomes important to visualize post-disaster scenarios at the planning stage so that the emergencies could also be managed without loss of time.



Eco link wildlife bridge conceptual plan



Eco link wildlife bridge conceptual section AA'

Fig. 6 Eco Link Bridge Conceptual Plan and Section

Eco Link underpass conceptual plan

Eco Link underpass conceptual section AA'

Fig. 7 Eco Link Underpass Conceptual Plan and Section

7.9.10 Years of experience has revealed that break down of road communication due to blockade of roads because of landslides and other mass movements often have serious implications, especially on strategic and high traffic roads. Some general guidelines to deal with road blockades have been provided in IRC: SP:48, For all known landslide hotspots, where threats of road blockades are persistent, and cost of recurring delays are huge, provision for a stretch of the emergency road shall be made an integral part of the plan.

7.9.11 Hazard levels on hill roads dramatically rise due to extreme weather events in the monsoon season. Rainfall triggers landslides which in turn kill people and block roads. Many of these hotspots are already known, and loss of lives can be prevented by an early warning.

7.10 Guidance at the Design Stage

7.10.1 The first major step of critical importance at the design stage is to be certain about the:

a) credibility of large scale single and multi-hazard maps for an understanding of the terrain, and risk assessment

b) adequacy, appropriateness and credibility of the site investigation data to cover all aspects of design

c) data gaps and uncertainties requiring assumptions to be validated during construction

d) hazard, vulnerability and risk analysis at critical locations along the route

e) lessons from past experience and history and distribution of hazards and vulnerable points along the route

f) micro-geological and hydro-geological details of the locations where deep cuttings or critical structures are involved, and

g) projected hazard scenarios due to factors such as extreme weather events and urbanisation with identification of infrastructure elements at risk.

7.10.2 The next major step would be to quantify safety levels of the site-specific slopes before construction to figure out objectively the consequences of construction in terms of altered levels of safety. This shall be achieved by stability analysis of in situ (virgin) slopes from top to toe vis a vis the stability analysis of the slopes at those very locations after introducing the proposed road sections including cuttings, embankments and cut-fill sections. The sections identified as unsafe shall thereafter be analysed in greater detail using the desired sequence/ stages of construction. The aim of this analysis would be to quantify margins of safety during the various stages of construction after arriving at the various tenable modes of failure. The slope protection works can then be designed to boost up the margins of safety to the desired levels. The package of slope protection works, a sequence of construction and the overall plan and a contingency plan will naturally follow.

7.10.3 Wherever quality data is unavailable, questionable or not credible, the connect between investigational data and design of protection works remains doubtful. In such cases, added investigations shall be commissioned to ensure that the slope design at highway cuttings and the related slope protection measures are intimately and logically connected with the

a) overall findings of geological, geotechnical and hydro-geological field and laboratory investigations;

b) the interplay of a site-specific chain of causative factors including anthropogenic factors and triggers of high-intensity short-duration rainfall, earthquake, etc., and

c) the results of the back analysis of the area-specific failed slopes, and landslides, if available.

7.10.4 For the desired degree of disaster resilience, margins of safety shall be fixed with due diligence after ascertaining the quality and credibility of data and after understanding the implications of uncertainties in design and construction and the consequences of failure. Margins of safety shall be high enough, both in the long and short terms to take care of:

a) interplay of individual hazards

b) the combined effect of two or more hazards, and

c) delayed and progressive failures.

Two or more types of hazards may strike a specific road location individually, concurrently, sequentially or in their various combinations. The project design shall take early note of all such possibilities.

7.10.5 Before arriving at a package of road protection measures for construction of green, resilient highways, need of such measures should be established through a rigorous analysis based on credible data. During the course of the design of road protection works, various possible options shall be shortlisted based on the current state of the art, the past area-specific history and experience, feasibility, institutional capacity, available expertise, economics and the available time frame. The relative merits and demerits of every competing option shall be documented. Based on the comparative evaluation, the final pick of the package of protection measures shall be made.

7.10.6 All site-specific problems being unique, one type of solution or technology cannot suit all sites. To illustrate the point, let us consider the DPR's of some of the hill road projects which tend to prescribe look- alike solutions for slope protection without ensuring their down to earth connection with the ground realities. For a given problem, there are usually several technically sound solutions. The final pick shall always favour the best solution/ technology out of the green technologies, blue and grey protection measures, if and when considered essential to boost the margins of safety further.

7.10.7 Stability analysis can be deterministic and probabilistic. Limit equilibrium approach is very common. In its use, designers have no choice other than to carry out stability analysis either in terms of total stress or in terms of effective stress. IRC:75 "Guidelines for the Design of High Embankments" published as far back as 1979 not only convey the fundamentals of stability analysis but demonstrate by actual examples of how different modes of failure could be meaningfully analysed. It is one of the few publications which remains as valid today. In this age, when computer software has taken over the designs without giving the designer the feel of the process, the aforesaid IRC Publication stands out as an example of the convincing power of step by step calculation.

7.10.8 In hazardous terrains with history, the disaster-resilient highway design should include fixing of route-specific landslides and slope failure, big or small, as an integral part of the design. If and when the presence of slope failures and landslides gets ignored, the route will continue to remain under the persistent threat of the living landslides. It is for this reason that, fixing of all known hazards such as flooding, ground subsidence, slope erosion, landslides, avalanches etc., shall be made mandatory in order to relieve the highway of the recurring threats both in short and the long term. Landslides often get reactivated because of anthropogenic activities like slope cuttings during road construction, surprising the highway engineer with an unforeseen set of problems. Whenever such a situation is faced, the extent of feasibility and the benefits of investment in permanently fixing of the landslides shall be determined by a multidisciplinary team of experts.

7.10.9 The philosophy behind the design of grey technologies like anchored retaining walls is to hold back the unstable slopes by providing external support besides releasing the hydrostatic pressure . On the other hand, green technologies aim at internally strengthening the unstable area to take on and resist the gravity- induced driving forces. For example, by effectively draining an unstable slope, the dissipation of excess hydrostatic pressures within it will lead to an increase of its shearing resistance, thereby restoring stability and delivering lasting benefits. Use of environment-friendly technologies not only restore stability but also rejuvenate slopes and restore green vegetative Cover.

7.10.10 For certification of the various road sections for safety, the current practice is to analyse the safety of Hillside, Median side and Valley side sections of the road. Such an exercise done in isolation is of limited value because, in real-life situations, slope failures could be large enough to take on hillside, median side and valley side all at the same time. There are also possibilities that failure on the hillside may provoke slope failure on the median side, which in turn may provoke and trigger slope failure on the valley side as a chain reaction. The reverse could also happen when the valley side slope fails to trigger failures in the upper reaches involving the median side and the hillside. The widely prevalent practice of looking separately at the hillside, median side and valley side stability at prescribed chainages along the highway route shall be replaced by stability analysis at all critical longitudinal sections considering anticipated modes of failures-whether progressive or retrogressive; shallow or deep; rotational or composite; planar or complex.

7.10.11 The design must include all modes and mechanisms to anticipate failures. Highways passing through a geologically complex, seismological active and ecologically fragile topography cannot be looked at, as packets in isolation, at the specified chainage points. The known multi-hazard history of the area and randomly dispersed recurring threats of known and new threats can destabilize the slopes at any location. Holistic assessment and remediation alone can provide the best assurance of safety by minimizing- slope failures, roadblocks, loss of lives and inordinate travel delays.

7.11 Guidance at the Construction Stage

7.11.1 At every critical stage of a major highway project in areas known to be hazardous, Independent Peer Reviews (IPRs) of the progress and Third-Party Inspections and Audits (TPIA) shall be encouraged and, where essential, made mandatory as an integral part of a project implementation strategy.

7.11.2 The regulations should be put in place to establish Public Committees with the desired levels of multidisciplinary expertise for auditing these activities, suggesting mid-course corrections and assisting the project at different stages of its implementation.

7.11.3 All the site-specific protective works shall be implemented in a prescribed sequence in a single working season. Slope protective works, if not well-engineered or those applied in piecemeal are often ineffective.

7.11.4 When passing through hazardous areas, the highways shall be pro-actively equipped with an emergency management apparatus ready to swing into action, if and when required. Management of traffic with timely alerts against rock falls, debris flows and other forms of landslides; protection of seemingly unsafe human settlements, towers and trees as well

as timely management of huge volumes of debris awaiting disposal for the avoidance of potential debris flows shall be a part of the assigned responsibilities. For all major GRH projects, instrumentation of, especially the vulnerable areas shall be carried out for real-time monitoring, data analysis for assessment of safety, early warning and timely preventive and protective actions.

7.11.5 Small road failures shall also be attended with the same alacrity as the big ones to prevent them from growing in size as an eventual threat to life and property. Every major slope failure and landslide can generally be traced to a minor slip or small slope movement, which could have been easily prevented by swift action at district and local levels.

8 TECHNOLOGICAL INNOVATION AND FUTURE TRENDS

8.1 GRH projects shall endeavor to adopt Intelligent Transport Systems (ITS) aimed at safety, efficiency, capacity, cost, comfort, convenience, degree of freedom from maintenance and sustainability. Poorly designed and constructed roads and their intersections, head-on-crashes, reckless and drunken driving, uncontrolled mixed traffic, traffic indiscipline, unchecked vehicular speeds and the slack techno- legal regime are often the cause of accidents. ITS safety technologies hold both promise and potential for enhancing road safety by reducing road accidents, fatalities and injuries.

8.2 A mix of vehicles using old and new technologies pose yet another challenge in blending the old and new infrastructure and standardization. Digital maps form the core of many ITS safety applications, yet the current quality of these maps leave much to be desired. Country-wide and regional efforts to develop consistent digital maps are strongly supported. These should form a basis and give impetus to rapid development and use of automated vehicle location technologies in safety applications. Our leading knowledge institutions will have to address all aspects of ITS quickly- innovation, functional ease and efficiency human-technology interface related issues, evaluation and cost-economics. The professional bodies like IAHE will have to develop well-integrated training programmes for the training of ITS and motivation through the sharing of experiences. Effective use of archival data generated by ITS technologies could lead to improved safety systems.

8.3 Structural road safety and traffic safety are both important. We need much improved, fail-free sensor technology, maintenance-free control devices, intelligent tools for managing complex traffic flows and user-friendly computer-systems to ensure road safety, traffic decongestion, fuel efficiency, reduced travel time and nearly a zero-maintenance road system.

8.4 The UAVs (Unmanned Aerial Vehicle) like drones now have multiple application areas and are great assets to the Highway engineer. Whether for identification and reaffirmation of potentially hazardous areas or gathering of real- time data especially on the management of large complex projects, drones are already emerging as cost- effective first choice. Where sorts of drones have inundated the global toy market, most countries, including India, have yet to formulate their UAV policies and the associated regulatory framework. The time is not very far when the technologies of interactive lights, electric priority lanes and glow-in-the-dark road linings will become ground reality.

8.5 The continuous influx of Smart Construction materials and technologies in the construction industry renews the hope that all the various foreseen risks to the resilience of roads

can be overcome if the highway designs could be made more robust through their judicious and timely use alongside other options at hand. This point can be illustrated by considering the common, serious problem of flooding of roads and parking lots, especially during the monsoon season. Even if the roads are designed following best of the practices, tropical cyclones and tidal waves in coastal areas or excess of overland flow due to extreme weather events in hilly areas or anthropogenic factors in urban areas could lead to their flooding. Simply speaking, the problems of inundation due to poor drainage and flooding even on the otherwise green highways and parking lots remain a matter of perennial concern. In such situations, ordinarily, highway engineers take recourse to corrective actions to improve drainage with a view to cutting down on the inundation period. There are many innovations in this area, and one such development relates to permeable concrete.

8.6 Some highways remain so busy that there is hardly any time left for their maintenance. Development of self-healing concrete is yet another smart material which has come as a ray of hope. The present trends favour autonomous infrastructure self-healing technologies capable of continuous monitoring and auto-repair of roads and road infrastructure for efficient maintenance. The three types of self-healing concrete technologies are

a) Shape-memory polymers activated by electrical current;

b) Healing agents made from organic and inorganic compounds; and

c) Capsules containing bacteria and healing agents.

Reportedly, the M4L trial by the School of Engineering at the University of Cardiff, in Wales, is underway at a road construction site near the A465 highway in South Wales, where the researchers can view the performance under real-world conditions.

8.7 The safety of roving construction workers who pave roads, paint road markings and inspect bridges are often threatened on busy roads. The driverless vehicles are conceived to serve as construction- site "crash trucks" as they eliminate the risk of harm in case a moving car hits the truck. Financing resilient infrastructure through government legislation can boost mainstreaming GRH in a big way.

8.8 Improved emergency response to bridge failures: There is an urgent need to improve response to bridge failures by using 3rd Generation Modular Panel Bridges. These can be launched quickly for use as temporary or permanent bridges. They can help bring down transportation costs substantially by quicker restoration of NHs to their full capacity. Due to inadequate response, it can take years to restore a NH to full capacity today, especially in hilly areas, along the borders. With 3rd Generation Modular bridges, in the same time frame as the Bailey Bridge, it is possible to have a new bridge to NH specifications, double-lane and designed to carry the specified IRC loads. These bridges are designed for a life of 100 years, as compared to 20-30 years for the Bailey bridge.

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